DECLARATION

The undersigned, translator, Master of Arts, graduated from the University of Turku,

HEREBY solemnly declares that the appended document in English is a true and faithful translation of application FI 20040070 filed with the Finnish Patent Office in the name of Elekta Neuromag Oy.

AND I make this solemn declaration sincerely believing it to be true.

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METHOD FOR SEPARATING MULTICHANNEL SIGNALS CAUSED BY AC AND DC SOURCES

FIELD OF THE INVENTION

The present invention relates to a new and advanced method to process the magnetic fields, or so-called DC fields, produced by time-independent currents, i.e. direct currents, of a study object in multichannel measurements. In particular, the present invention relates to a new manner of eliminating harmful DC fields caused by the movement of the study object and, on the other hand, to a manner of studying interesting DC fields.

By time-independent, static DC sources, DC fields and direct currents are meant, in the context of this invention, completely static phenomena as well as those alternating at a frequency of up to one hertz.

BACKGROUND OF THE INVENTION

Magnetometers, for example SQUID sensors, are normally used to measure biomagnetic signals, these magnetometers being sensitive only to dynamic phenomena. Thus, the direct currents of an object that is immovable relative to the sensor array do not produce a measurement signal, and the only way to measure the direct currents is to move the object relative to the sensor array or to move the sensor array relative to the object. In this case, the magnetic field distribution that is static in the coordinate system of the object and that is produced by the direct currents of the object changes as a function of time in the coordinate system of the sensor array and thereby produces a measurement signal changing as a function of time.

The direct currents that produce DC fields are not often interesting, but for example magne-

toencephalographic, i.e. MEG, measurements used for studying the human brain involve situations where detection of the direct currents is desirable. For example, the epileptic, migraine and REM sleep phenomena are associated to interesting direct currents.

In addition to DC fields caused by physiological direct currents, DC fields are caused by all magnetized bodies that are immovable in the coordinate system of the object. These may include for example small magnetic particles left in the skull from a drill used for brain surgery, braces as well as magnetic impurities for example in the hair. These magnetizations typically induce, when the object is moving, an interference signal which is very strong in comparison to the biomagnetic signal, and the elimination or damping of which is essential to detect the physiological phenomenon to be studied.

The problem is typical particularly in clinical measurements for measuring patients who find it difficult to stay completely immovable for the duration of the measurement. In addition to MEG measurements, the DC fields produced by direct currents can be significant for instance in magnetocardiographic, i.e. MCG, measurements conducted to study the activity of the heart, where magnetized particles produce the measurement signal e.g. as a result of respiratory movements.

A method where the subject is moved in a geometrically known fashion, for example periodically at a known frequency and amplitude, relative to the measuring device has been used to detect the physiological direct currents. One such method is described for instance in publications "Measurement of near-DC biomagnetic fields of the head using a horizontal modulation of the body position", Wuebbeler et al, Recent Advances in Biomagnetism, Sendai, pp. 369-372, 1999, and "Hyperventilation-induced human cerebral magnetic

fields non-invasively monitored by multichannel 'direct current' magnetoencephalography", Carbon et al, Neuroscience Letters, Vol. 287, pp. 227-230, 2000. In the cited method, the subject lies on a bed that is movable relative to the sensor array such that the head of the subject is supported to be immovable relative to the bed. This must be made so that the movement of the head could be expected to correspond to the known movement of the bed. The bed is moved sinusoidally at a frequency of 0.4Hz and amplitude of 75mm, whereupon the direct currents of the head appear in the measurement signal at a modulation frequency of 0,4Hz. The signals are demodulated and reconstructed in such a way that the DC signals can be easily studied.

The above method is directed to the measurement of interesting physiological direct currents by a magnetoencephalographic device. In the method, the separate movement of the head is prevented and the movement that is necessary for detection of the DC signals is produced by a separate medium, i.e. the bed. In this case, the magnetization proper to the bed also produces a modulation frequency signal that, being an interference signal, must be eliminated for example by moving the bed in a corresponding manner without the subject and by measuring the resulting DC signal as a reference.

The method described above includes many problems and limitations. Securing the head of the subject can be experienced as unpleasant particularly in the case of patients in poor health. In addition, the movement of the bed produces the above-mentioned interference signal, the elimination of which, together with the construction of the mechanical movement system and preparations for the DC measurements, requires plenty of additional work in comparison to the

normal MEG measurement. The method is thus extremely vulnerable to interference.

There have not been proposed procedures to eliminate the interference signals caused by 'additional' DC fields of the moving subject relating to the conventional MEG measurements that would be based on the DC property of the interference sources. The interference elimination methods do not observe the movement of the subject, but only aim at eliminating from the measurements the interference signal caused by the movement by standard methods. This can be performed for example by high-pass filtration, but this way the slow brain signals are also lost.

OBJECTIVE OF THE INVENTION

The objective of the invention is to eliminate the drawbacks referred to above or at least significantly to alleviate them. In particular, the objective of the invention is to disclose a new type of a method for studying the physiological, interesting DC fields of a subject, on the one hand, and for eliminating the distortions in the measurement signal caused by 'additional' DC fields in a conventional MEG or MCG measurement, on the other. Furthermore, the objective of the invention is to disclose a solution for studying interesting DC fields without special test arrangements and enabling the free movement of the head of the subject.

For characteristic features of the present invention, reference is made to the claims.

DESCRIPTION OF THE INVENTION

The present invention relates to a novel manner of measuring DC fields by a multichannel MEG or MCG measuring device and, on the other hand, to a manner of eliminating from the measurement result the interference signals caused by direct currents. In the

invention, a tracking system for the movement of the subject as well as a movement correction method for the measured signals are combined in such a way that the signals caused by the direct currents of the moving subject appear in the final measurement result as a static signal component in a conventional MEG or MCG measurement. In this case, no special preparations for measuring the DC fields need be made in advance in the measurement. The above-mentioned movement tracking system is described in patent application PCT/FI02/00225, and the movement correction method is described in patent application FI20030392. They are incorporated in this application by this reference.

The basic idea of the invention is tracking the movement of the head of the subject and modeling the movement of the head as the movement of the sensor array around an immovable head. The measured magnetic field signal is represented as elementary fields in a signal space basis where the basis vector coefficients are attached to the coordinate system of the head by utilizing information about the geometry between the head and the measuring device. In this case, the time behavior of the basis vector coefficients does not include the distortion caused by the movement of the head, but the same basis vector coefficients would have been obtained also from a completely immovable head with the distinction that, in the immovable case the coefficients would not encompass a DC component because the SQUID sensors do not measure static phenomena. As the head moves relative to the measuring device, a signal caused by direct currents appears in the measurement signal, the time behavior of which in a movement-uncorrected measurement corresponds to the movement of the head. As a result of the above-mentioned movement tracking and correction method, the observed signal caused by the direct current appears in the basis vector coefficients as a static signal

because, in the coordinate system of the head, the direct currents produce a static signal.

In calculating the elementary fields, a preferred embodiment is to use spherical harmonics, in which case it is possible, at the same time, easily to eliminate the part of the external interference fields as presented in patent application FI20030392. The movement correction may also be conducted by other manners, for example utilizing the minimum-norm estimate of the current distribution of the study object.

Thanks to the invention, the processing of the signals caused by direct currents is very easy. To study the physiological direct currents, the subject can be asked freely to move their head, in which case, as a result of movement correction, the DC component of the measurement signal includes only the signal produced by fixed direct currents in the head of the subject. The DC component can be separated for example by Fourier transform.

The DC signal obtained by the above manner is, of course, the sum of all signals produced by direct currents and includes, in addition to physiological DC signals, the DC signals to be classified as potential interference sources, such as magnetic impurities, that must be separated from the physiological signals by some method. The elimination of DC interference from movement-corrected data is very easy when the physiological DC signal is not the study object, because the DC signal can be simply eliminated by so-called baseline correction. In this correction method, the mean value of the signal is calculated by each measurement channel for a time period during which the biomagnetic response is not present. In this case, the mean value corresponds to the DC level of the channel that can be eliminated for the entire measurement period by subtracting the numerical value of the particular DC level from the measurement signal.

The invention also allows a novel manner of positioning the measurement object relative to the measuring device. Since magnetized bodies produce a signal corresponding to the movement of the object, it is possible to attach magnetic bodies to the object, to the positions that are known in the coordinate system of the object, and to measure the movement of the object based on the movement signals of the bodies. In this case, the movement tracking system corresponds to the method described in patent application FI20010558 with the distinction of using static signal transmitters and being able to perform the positioning, as desired, directly from the spatial distribution of the movement signals without time integration, whereby a considerably faster, practically real-time, movement tracking system is achieved.

By virtue of the present invention, it is possible to study the physiological, interesting DC fields of the subject, on the one hand, and to eliminate the distortions in the measurement signal caused by "additional" DC fields in the conventional MEG or MCG measurement, on the other. Thanks to the invention, no special arrangements are needed in these studies, but the solution according to the invention in combination with the conventional measurements provides the possibility of studying the direct currents. Furthermore, the invention also enables the free movement of the head of the subject in the measurement of DC fields.

LIST OF FIGURES

In the following section, the invention will be described in detail by means of examples with reference to the accompanying drawing, in which

Fig. 1 schematically represents one measurement arrangement according to the present invention, and

Fig. 2 is a flow chart of one embodiment of the method according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Fig. 1 represents one preferred measurement arrangement according to the invention. Fig. 1 schematically illustrates a multichannel magnetometer 1 designated for measuring the magnetic fields of the brain. The magnetometer includes a cooled vessel, such as a dewar 2, containing a set of individual magnetometers, i.e. SQUID sensors 3, at a low temperature. Provided to the study object 4, in this context to the surface of the head of the subject, is a set of signal sources 5, the position of which in the coordinate system A of the measurement object is known. When the position of the signal sources is known, it is possible to detect the position of the signal sources and also the position of other signal sources present in the measurement object, particularly the interesting biomagnetic signal sources, by measuring with the sensor array 3.

When the measurement object 4 moves, for example according to arrows M_1 and M_2, the signal sources 5 move as well, in which case the sensors 3 also register the magnetic fields generated by direct current. Thus, the signal sources may be alternating current as well as direct current sources.

Next, the operation of the invention will be described with reference to Fig. 1 and 2. The patient can be asked to move their head relative to the measuring device 2, for example in the direction of arrows M_1 and M_2, step 22. The movement can be free and need not be predetermined. The movement is registered by the sensor array 3, step 23, by utilizing the signal sources 5 provided to the head of the patient. The DC sources 6 on the head of the patient that may relate to interesting biomagnetic phenomena or magnetic bod-

ies produce a direct current component to the magnetic field in the coordinate system of the head, which is registered by the sensors 3 due to the dynamics caused by the movement of the head. This direct current component observed can be separated from the measurement signal when represented by elementary field components attached to the coordinate system of the head, taking into account the observed movement, in which case the DC component appears as a static signal, steps 23, 24 in Fig. 2. The elementary fields can be generated for example by means of spherical harmonics represented in the coordinate system of the head.

The invention is mot limited merely to the embodiments presented above; instead, many variations are possible within the scope of the inventive idea defined by the claims.

CLAIMS

1. A signal processing method for separating a signal relating to a static source present in a measurement object from a signal registered by a measuring device that measures a dynamic phenomenon, in which method the measurement object and the measuring device move relative to each other, c h a r a c t e r i z e d in that

the relative movement of the measuring device and the measurement object is determined,

the signal is represented in a coordinate system attached to the measurement object, in which case the signal produced by the static source is observed as a static signal, and

said static signal is separated from the measurement signal.

2. The method according to claim 1, c h a r a c t e r i z e d in that the relative movement of the measuring device and the measurement object is determined in real time when the measurement signal is being registered.

3. The method according to claim 1, c h a r a c t e r i z e d in that

the movement of the measurement object is modeled as movement of the measuring device around the measurement object, and

the registered signal is represented as elementary fields in a signal space basis, the basis vector coefficients of which are attached to the coordinate system of the measurement object based on the known geometry between the measurement object and the measuring device.

4. The method according to claim 3, c h a r a c t e r i z e d in that the elementary fields are calculated by spherical harmonics.

5. The method according to claim 1, c h a r a c t e r i z e d in that the determined movement is ad-

justed by using the minimum-norm estimate of the current distribution of the measurement object.

6. The method according to claim 1, c h a r a c t e r i z e d in that the DC signal is separated from the measurement signal by high-pass filtering.

7. The method according to claim 1, c h a r a c t e r i z e d in that

the measurement signal is divided into two time periods,

said static signal is separated from either one of the time periods,

the difference between the original signal and the separated static signal is calculated for the total time period.

8. The method according to claim 1, c h a r a c t e r i z e d in that, in connection with a neuromagnetic MEG measurement, the relative movement of the measuring device and the measurement object is provided by the person to be studied moving their head on purpose.

9. The method according to claim 1, c h a r a c t e r i z e d in that

the signal produced by the magnetic bodies attached to the measurement object is measured, the position of the bodies in the coordinate system of the measurement object being known, and

the position of the measurement object relative to the measuring device is determined by these measurement signals.

10. The method according to claim 1 for reducing the interference caused by the movement of static magnetization in a biomagnetic signal, c h a r a c t e r i z e d in that the registered signal is high-pass filtered before and after representing the signal in the coordinate system attached to the measurement object.

TIIVISTELMÄ

The present invention relates to a novel manner of measuring direct current fields by a multichannel MEG or MCG measuring device and, on the other hand, to a manner of eliminating from the measurement result the interference signals caused by direct currents. In the invention, a tracking system for the movement of a subject as well as a movement correction method for the measured signals are combined in such a way that the signals caused by the direct currents of the moving subject appear in the final measurement result as a static signal component in a conventional MEG or MCG measurement. In this case, special preparations for the measurement of DC fields need not be made in advance in the measurement.

(Fig. 1)

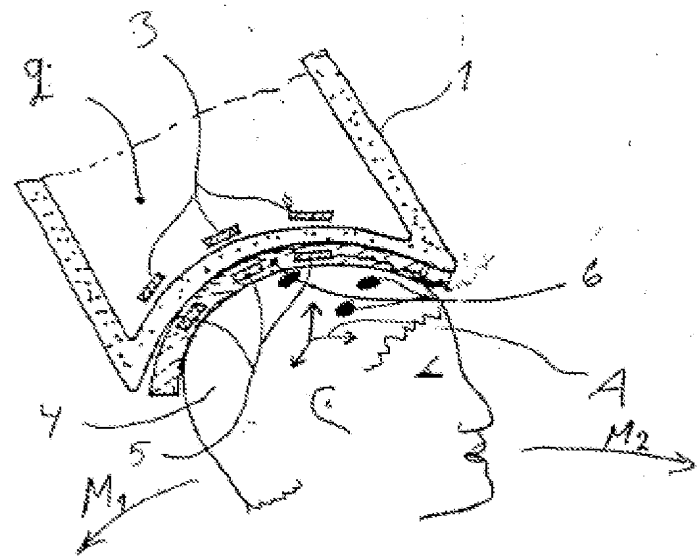
9
3
1
6
A
4
5
M_1
M_2

Fig 1

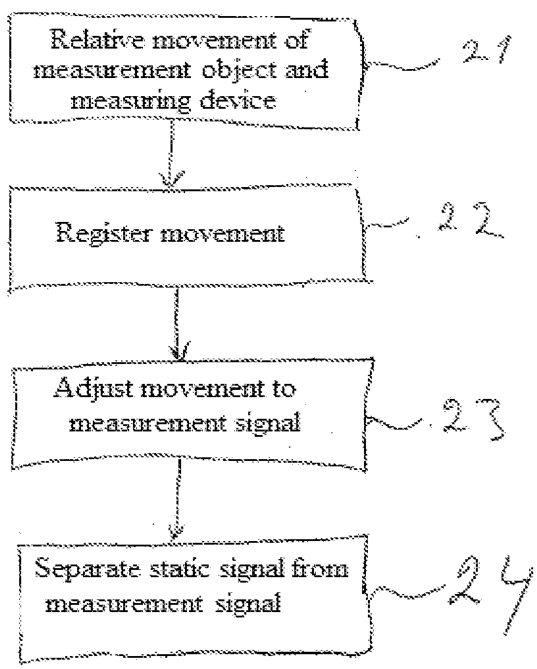
Relative movement of measurement object and measuring device
21
Register movement
22
Adjust movement to measurement signal
23
Separate static signal from measurement signal
24

Fig 2